U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

High Efficiency Modular Chemical Processes (HEMCP)

Modular Process Intensification Framework for R&D Targets

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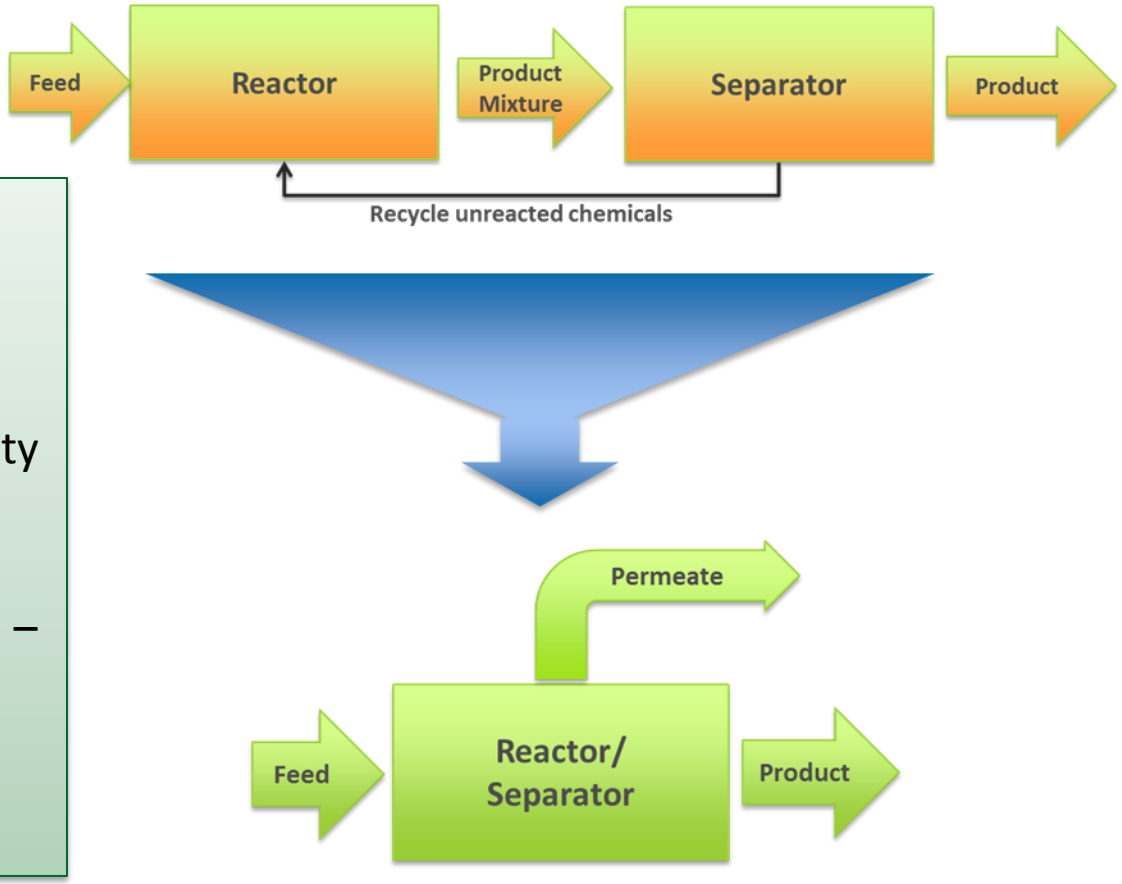
Presentation Outline

1. What is Process Intensification?
2. DOE's Approach to Process Intensification
3. Opportunity for Cross-Cutting High-Impact Research
4. Goals of the Process Intensification Institute
5. Addressing the 5 EERE Core Questions

What is Process Intensification (PI)?

Rethinking existing operation schemes into ones that are both more precise and more efficient than existing operations



Resulting in…

- Smaller equipment, reduced number of process steps
- Reduced plant size and complexity
- Modularity may replace scale up
- Reduced feedstock consumption – getting more from less
- Reduced pollution, energy use, capital and operating costs

Vision of the Process Intensification Institute

This institute will bring together US corporations, national laboratories and universities to collaborate in development of next generation, innovative, simple, modular, ultra energy efficient manufacturing technologies to enhance US global competitiveness, and positively affect the economy and job creation

"This institute will provide the shared assets to help companies, most importantly small manufacturers, access the capabilities and equipment to design, test, and pilot new chemical products and manufacturing processes." --President Obama

Create the foundation to continue PI development and PI equipment manufacturing in the U.S. and support the development of **new innovative business models**

Enable a **50% to 70% reduction** in waste, energy use, and capital and operating costs when compared with existing state of the art of processes.

Process Intensification Marketplace Impacts

Lower costs via flexible response to feedstock availability, use of domestic feedstocks, improved scale-ability and modularization, and elimination of costly infrastructure (like pipelines)

Improved product quality from quicker demand response and greater precision

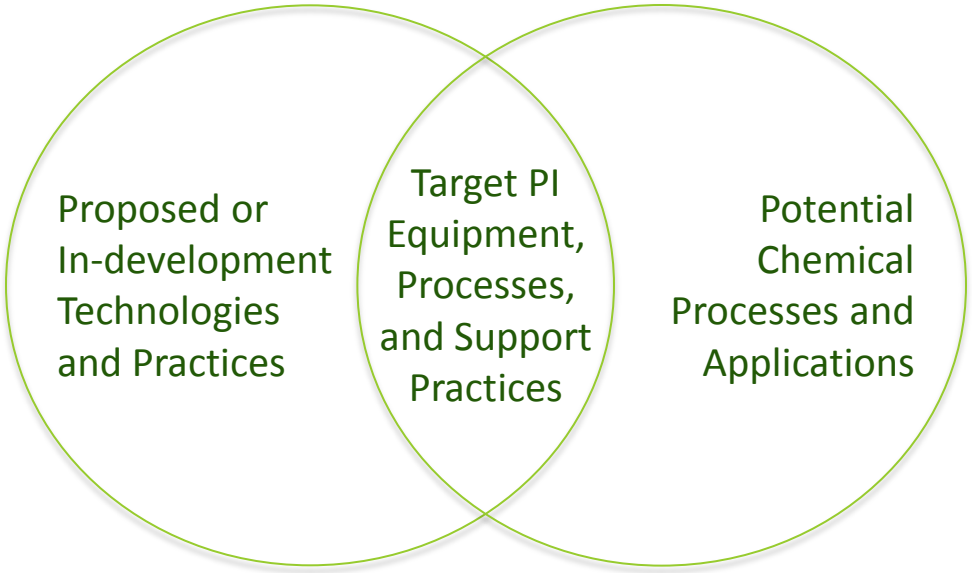
Better business case for domestic manufacturing due to improved costs, increased efficiency, and flexible capabilities

Common standards for interoperability and performance measurement

Improved communications between stakeholders, along supply chains, and between collaborators

Institute Approach to Process Intensification

The Institute will target key development areas to identify, research, and deploy process intensification opportunities that will benefit multiple manufacturing sectors



Our Approach

Two-pronged Attack:

1. Develop equipment, processes **AND** supporting services
2. Focus on chemicals processing areas that give the highest impact

Proposed objectives to overcome the technical challenges facing chemical processing

Design of 'plug-and-play' modular, continuous, PI technology at industrial scale for commercial applications, capable of widespread implementation throughout the U.S. industrial sector

Validation of continuous modular processes for new/enhanced reactor and separation technologies, new automation technology, and components fabricated through advanced manufacturing techniques

Establishment and dissemination of open-source design methodologies and guidelines for modular, container-based production units, applying process intensification concepts and innovative decision tools

Institute Approach to Process Intensification: Modularity

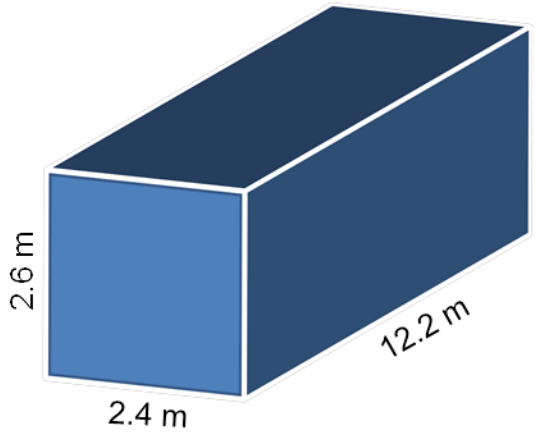
Leveraged Innovations

Reactor Engineering
- process intensification
- integrated processes
- novel catalysts

Manufacturing
- additive manufacturing
- crowd sourcing
- experience learning

Automation
- novel sensors
- data informatics
- control optimization

Chemical Process Module

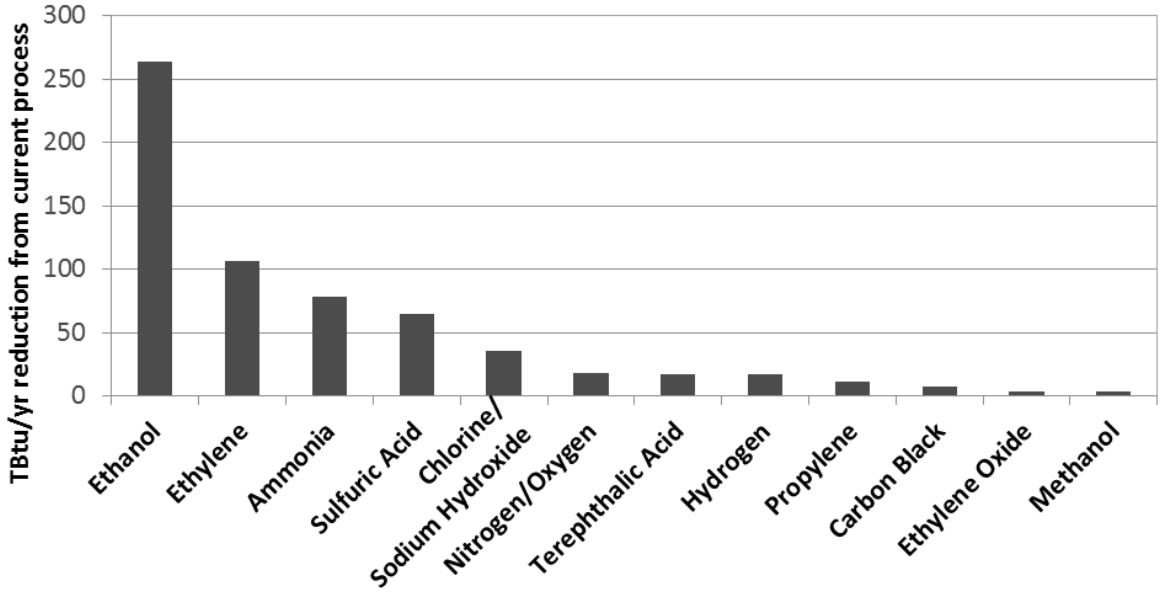


- plug-and-play, deployable containers
- uniform inputs/outputs
- mass-manufactured
- high process intensity and efficiency
- low environmental waste and capital cost

Modularity is a key aspect of PI technologies reducing the size and complexity of chemical plants, lowering the costs and risks associated with them, and making their deployment more responsive to fluctuations in market conditions

Process Intensification Opportunity as Identified in Chemicals

Process intensification energy savings opportunities in the chemicals industry (TBtu/yr)



Current Annual Onsite Energy Consumption[1]
1,152 TBtu/yr
63% of industry

Potential Energy Savings with Research[1]
628 TBtu/yr

Potential Cost Savings[2]
$8.221 billion/yr

PI target areas, applications, and energy reduction opportunities

- Advanced Heat Recovery/ Heat Exchange
- Modular Systems Design and Integration
- Alternative Process Energy Sources
- Novel Separations/ Distillation Alternatives
- Integrated Process Steps (i.e. reactions and separations)

Using updated energy consumption figures from 2014 U.S. Chemical Industry Energy Bandwidth Study (2010 data from MECS) we can target the most energy intensive chemicals and identify opportunities for process intensification efforts

[1] *Energy Use Bandwidth Study: U.S. Chemical Industry (draft),* prepared for U.S. Department of Energy, Advanced Manufacturing Office. 2014.
[2] Based on a simplified value of $13.091 / MMBtu (calculated average of the industrial price of electricity and natural gas) EIA 2014: http://www.eia.gov/electricity/annual/html/epa_01_01.html and http://www.eia.gov/dnav/ng/hist/n3035us3m.htm

Cross-Cutting from Chemicals

Chemicals offer cross-cutting opportunity to target key areas in manufacturing that will result in widespread and enduring benefits

Development of PI Technologies and Practices – Chemicals Focus

The chemicals sector offers a strong foundation for the PI Institute due to it's significant energy consumption, identified opportunities, and applicability to other manufacturing sectors. For example, lower energy and cost effective alternatives to distillation for the separation of alcohols would have a significant impact on oil & gas extraction, biofuels, and petroleum refining in addition to many major chemical production pathways.

Opportunity for the Development of PI technologies in the Chemicals Sector:

- Novel separations
- Improved reaction kinetics
- Steam reforming of natural gas
- Advanced heat transfer and recovery
- Integrated process steps
- Development of modular processes

PI Cross Cutting Industries and Applications

Power Generation
- Air separation
- Hydrogen Generation
- Gasification
- Carbon Capture

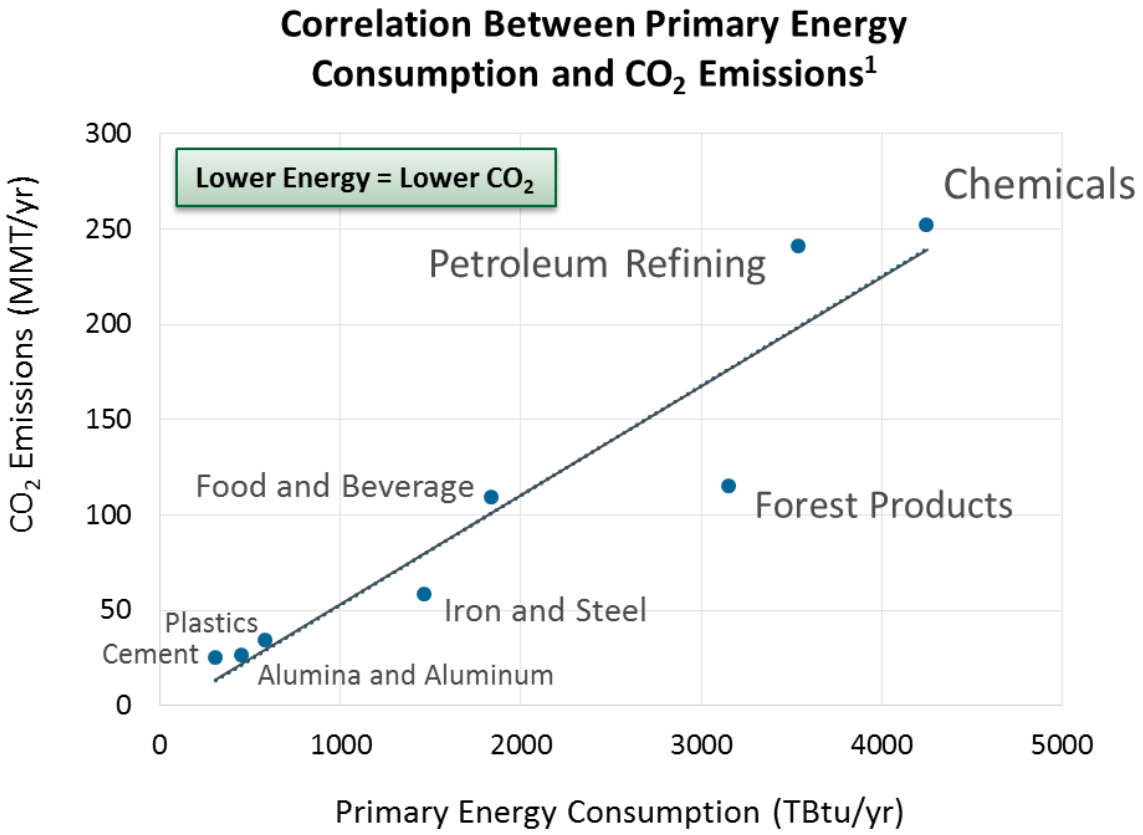
Oil & Gas Extraction
- Well-head gas separation (N2, CO2, C2+, SO2, Ar, H2O)
- Helium recovery and refining
- Hydro-fracturing water recycling
- Natural gas pipeline processing

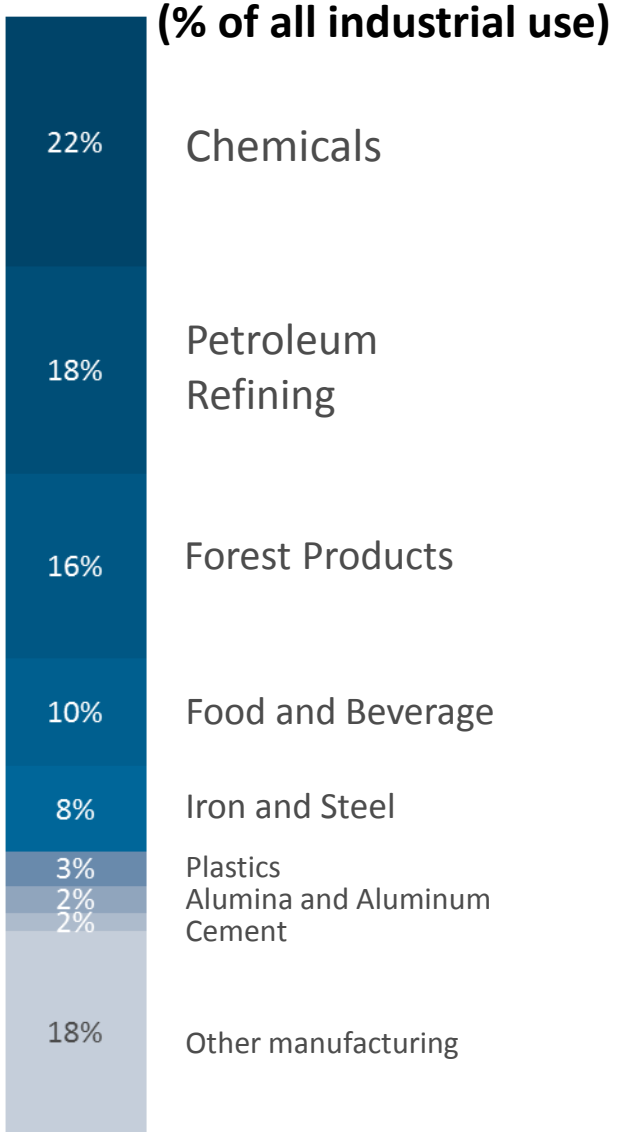
Biofuels
- Separations
- Improved Reactions
- Distillation
- Gasification
- Integrated Processes
- Production Flexibility
- Biofuel upgrading

Petroleum Refining
- Crude oil upgrading
- Gas to liquid (fuels and chemicals) conversion
- Fractional distillation
- Steam reforming of natural gas
- Wastewater collection and treatment

Waste & Recycling
- Anaerobic Membrane Digesters
- Desalination
- Water and sewage treatment
- Metal recycling
- Electronics recycling

Energy Consumption and GHG Emissions





Industrial sources consume nearly 20,000 TBtu of primary energy annually

The chemicals and petroleum refining sectors constitute 40% of the energy consumed in industrial manufacturing and offer cross-cutting opportunities for improvements

[1] Manufacturing Energy and Carbon Footprints. Advanced Manufacturing Office. February 2014. http://energy.gov/eere/amo/manufacturing-energy-and-carbon-footprints-2010-mecs

Goals of the PI Institute

Demonstrate at least three modular processes that, when compared with current large-scale industrial processes, meet the target metrics

Establish baselines for industrial standards for each process that will undergo PI development efforts

Two modeling efforts will be completed to support the baselines and confirm opportunities for PI Development

1. Series of mass and energy balance calculations
2. Incorporate PI improvements for each process, such as integrated reactions & separations, to validate opportunities and estimate cost impact

Key Manufacturing Improvement Areas

Basic manufacturing: Improved standards, tolerances, materials compatibility, and small/micro components

Basic chemical processes: Thermodynamic efficiency, catalysts development and improvement, novel separations techniques, and combination of process steps

Integration and scale-up: Interoperability and parallel development of supporting systems, data modeling and sensors, and capacity and throughput issues for manufacturing of parts and plants

Impact Area	Metric Comparable to Large-Scale Industrial Standards
Cost Reduction	1000x less capital cost ($) at cost parity per unit output [$/(kg/s)]
Modular Systems/ Equipment Size Reductions	70 m^3 modular unit volume (8' x 8' x 40x')
Energy Efficiency	Comparable production energy (kg product/ kJ)
Environmental Impact	Minimum of 20% lower emissions/ environmental waste (kg/kg)

Addressing the 5 EERE Core Questions

High Impact

Developments will facilitate energy savings, cost reductions, and process improvements that have a broad applicability to other manufacturing sectors

Additionality

The Institute will be designed to encourage and leverage the crosscutting nature of a collaborative environment where knowledge, risk, and costs are shared to integrate and commercialize PI technologies and practices

Openness

The vision, focus, and key target areas of the PI Institute have been crafted with, and will continue to be shaped by, the input of various stakeholders

Enduring Economic Benefit

Improvements will enable customized plants, increased localized production, greater utilization of U.S. feedstocks, and more efficiently serve U.S. demand; spurring investment in U.S. infrastructure, resulting in more jobs and increased U.S. competitiveness

Proper Role of Government

The government will identify and maintain a high level vision for the development and widespread applicability of these technologies that is beyond the scope of individual private sector organizations

Thank You

Thanks for Listening

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